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Reverse Logistic Strategy for the Management of Tire Waste in Mexico and Russia: Review and Conceptual Model

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Abstract: Management of tire waste is an important aspect of sustainable development due to its environmental, economical and social impacts. Key aspects of Reverse Logistics (RL) and Green Logistics (GL), such as recycling, re-manufacturing and reusable packaging, can improve the management of tire waste and support sustainability. Although these processes have been performed with a high degree of efficiency in other countries such as Japan, Spain and Germany, the application in Mexico and Russia has faced setbacks due to the absence of guidelines regarding legislation, RL processes, and social responsibility. Within this context, the present work aims to develop an integrated RL model to improve on these processes by considering the RL models from Russia and Mexico. For this, a review focused on RL in Mexico, Russia, Japan and the European Union (EU) was performed. Hence, the integrated model considers regulations and policies performed in each country to assign responsibilities regarding RL processes for the management of tire waste. As discussed, the implementation of efficient RL processes for the management of tire waste depends of different social entities such as the user (customer), private and public companies, and manufacturing and state-of-the-art approaches to transform waste into different products (diversification) to consider the RL scheme as a total economic system.

Keywords: tire waste management; reverse logistics; green logistics; Mexico; Russia

1. Introduction

Logistics is defined as the element of the supply chain process that plans, implements and controls the efficient and effective flow and storage of goods, services and related information from the point of origin to the point of consumption to meet the needs of the client [1,2]. In recent years, Logistics has grown in complexity by opening its doors to a greater number of factors such as society, economics, social responsibility, sustainability and the environment. In this regard, concerns about environmental care have become an important factor, not only for the business sector, but also for society, government and social organizations.

This has paved the way for the concept of Green Logistics and Reverse Logistics:

- Reverse Logistics (RL) encompasses all the logistic activities from used products which are no longer required by the users to products again usable in a market. Within the environmental context, RL has been successfully applied for recovery, recycling and reuse of end-of-life electrical and electronic equipment [3–5]. Figure 1 presents the basic activities or processes in an RL system [6].

- Green Logistics (GL) is focused on restricting damage to environment during the process of Logistics. It is based on the global environment maintenance and sustainable development [7–10].

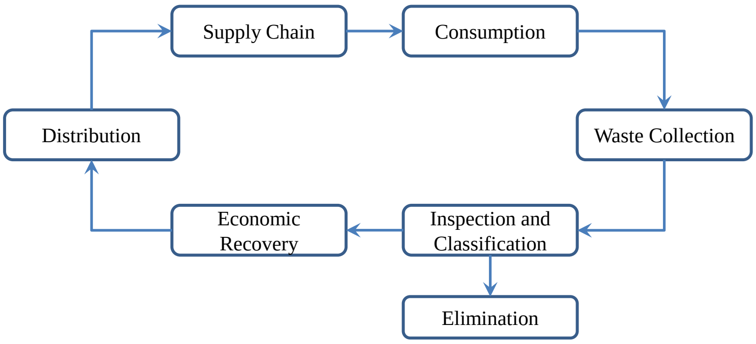

Figure 1. Basic activities in a Reverse Logistics (RL) system [6].

At present, the term GL is often used interchangeably with RL. However, in contrast to RL, GL resumes logistic activities that are primarily motivated by environmental considerations [11]. The most significant difference is that RL focuses on saving money and increasing value by reusing or reselling materials to recover lost profits and reduce operating costs; in turn, GL focuses on the transportation [8]. GL looks for alternatives so that the transport factor is favorable and the related costs are reduced, in addition to providing a green image for the company [12]. The activities considered are designed to measure environmental impacts on transportation, reduce energy consumption and reduce the use of materials. As presented in Figure 2, recycling, remanufacturing, and reusable packaging are the common processes that contribute to GL and RL. As discussed in [13], these processes have the most significant negative impacts on sustainability.

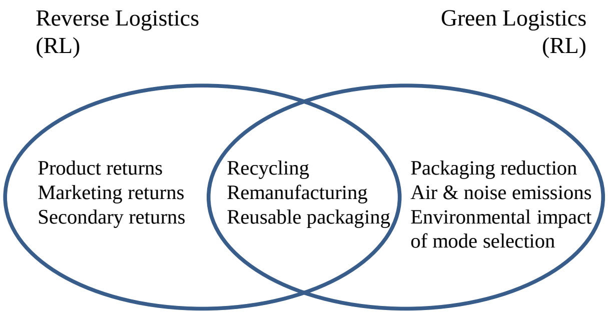

Figure 2. Comparison between Green Logistics (GL) and Reverse Logistics (RL) [8].

Hence, efforts to achieve sustainability within the supply chain should be focused on these processes. Particularly, tire waste management involves RL processes than can be improved to achieve sustainability.

The massive manufacture of tires and the difficulties to proper handling, once they have been used, constitute one of the most serious environmental problems of recent years at a worldwide level. This is because a tire needs large amounts of energy to be manufactured, and, in order to prevent it from being part of clandestine dumps, it requires a specialized recycling process after the end of its useful life [14].

Hence, management of tire waste is an important aspect of sustainable development due to the following environmental aspects [15,16]:

- as transport is one of the main logistic activities, there is an increasing demand for new tires and generation of scrap tires (end-of-life tires). Globally, an estimated one billion tires reach the end of their useful lives every year;
- scrap tires are usually shredded and disposed of in landfills, or stockpiled whole. Stockpiling leads to two significant hazards: it creates an ideal breeding ground for disease-carrier fauna, and fires;
- the void space of tires in landfills capture explosive methane gas which can represent a fire hazard, contaminate local water systems, and damage the landfill liners;
- chemical components such as stabilizers and flame retardants added to tires can kill advantageous bacteria in the soil.

Commonly, car owners take their worn tires to the tire shop, where they are replaced by new ones. Then, after the store has accumulated a certain number of tires, they are taken out of the store. Depending on the economic conditions, worn tires can be restored, transformed into energy, transformed into a new product, or buried [17]. Figure 3 presents the various stages of the life of a tire, from the acquisition of the raw material to its manufacture, use, and disposal [18].

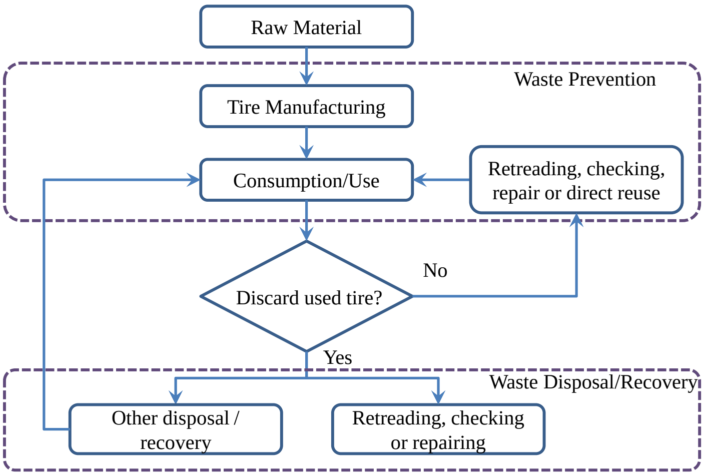

Figure 3. Stages of the life cycle of a tire [18].

However, RL processes in all industries are not widely performed. This is due to not enough knowledge about methodologies and tools to perform integrated Green-Reverse Logistics. In order to be sustainable, GL must consider environmental factors such as pollution, noise and climate change, which must keep a balance with economic and social factors. This can be achieved through RL as it influences the reduction of environmental impacts and the recovery of economic value. Particularly, within the manufacturing and transportation industries, RL and GL have become very important to reduce contaminants (chemical waste, CO_2 emissions, etc.).

In the specialized literature, different processes and strategies have been proposed to improve on sustainable practices to increase recycling rates of tire waste and reduce landfilling. Table 1 presents a review of some of the most significant proposals.

In general, most of the research has been performed on technical aspects of recycling processes and not on the management of RL processes. In this regard, recycling is one of the elements within a waste management system and an effective waste management system is crucial to address the problems caused by used tires.

Table 1. Works developed on sustainable processes and strategies for tire waste management (own work).

Work	Year	Journal	Type of Contribution	Focus
[19]	2018	Procedia CIRP (College International pour la Recherche en Productique)	Strategy	Determination of differences between tire waste recycling practices in South Africa and the European Union to improve on Reverse Logistics (RL) management.
[20]	2018	Resources, Conservation & Recycling	Process	Processing strategy of tire waste into activated carbon.
[21]	2018	Journal of Cleaner Production	Strategy	Study on the implementation of the extended producer responsibility scheme for tire waste in Colombia to improve on RL management.
[22,23]	2017–2018	Resources, Conservation & Recycling—Waste Management	Process	Study on the processing of recycled tire waste to be used as polymer modifier to improve strength of epoxy based composites.
[24]	2017	Coke and Chemistry	Process	Study on the use of tire waste in coke production.
[25]	2017	Journal of Cleaner Production	Process	Study on the application of recycled tire crumbs as insulator in lightweight cellular concrete.
[26]	2017	Journal of Cleaner Production	Process	Study on the processing of polymer-rubber composites from tire waste to obtain environmentally friendly materials.
[27]	2017	Environmental Research	Process	Processing strategy of tire waste into biofilm for wastewater treatment systems.
[28]	2017	Renewable and Sustainable Energy Reviews	Process	Processing strategy of tire waste into electric energy.
[29]	2017	Journal of Material Cycles and Waste Management	Strategy	Study on the management of tire waste recycling in Taiwan.
[30]	2015	Waste Management	Strategy	Study on the management of tire waste recycling in Italy and Romania.
[31]	2006	International Journal of Environmental Technology and Management	Strategy	Study on the management of RL processes for tire waste recycling in the United States of America.

As reported in [32], there are five key factors highlighted by the United Nations that must be present for the establishment of waste management systems:

- policies and regulations;
- supporting institutions;
- proper financial mechanisms;
- stake holder participation; and
- supporting technologies.

As reviewed in Table 1, there have been works on the analysis and development of strategies for tire waste management considering these factors in specific countries [19,21,29–31]. Thus, regional legislation plays an important role in the successful implementation of these strategies.

In this context, the present work is focused on developing a conceptual RL model for the tire waste management systems of Mexico and Russia due to an absence of works and consensus regarding RL strategies in these countries. While finding a better strategy cannot be assured due to different regional conditions of financial mechanisms, regulations, involving entities and technologies in each country, the contribution of the proposed RL model consists of the following:

- review of the factors (i.e., policies and regulations, supporting institutions, financial mechanisms) regarding the current tire waste management strategies in the EU, Japan, Mexico and Russia;
- analysis regarding the most important RL processes in these strategies associated with economic and sustainable benefits;
- development of a conceptual integrated RL model with these processes. The proposed RL model is focused on re-manufacturing or retreading and diversification to make it economically accessible and sustainable.

The advances of the present work are structured as follows: in Section 2, a review of the organization aspects of RL is presented. Then, in Section 3, the background of the RL processes and regulations in Russia, Mexico, the European Union (EU) and Japan are reviewed and discussed. The proposed conceptual RL model, which is focused on re-manufacturing and diversification, is presented in Section 4. State-of-the-art diversification techniques which can also be considered by general RL schemes are also presented. Finally, in Sections 5 and 6, the outcomes of the proposed model and conclusions are discussed.

2. Organizational and Managerial Aspects of Reverse Logistics in Companies

The RL process within companies requires the design, development and efficient control of a system to collect the out-of-use product and deliver it to the recovery entity that will apply the most appropriate management option for its optimal use. For this purpose, RL management must be supported by strategic, tactical and operational decisions (see Table 2). However, the application of these decisions and the overall development of RL will depend of the available reuse, re-manufacturing, or recycling systems for the out-of-use products. Thus, the development of RL can depend on [6]:

- The existence or absence of a traditional logistic system which can allow the reverse function.
- The type of product of interest in terms of its technology, ease of recovery, level of standardization, technical characteristics, etc.
- The recovery option (recycling, re-manufacturing or reuse) that will be applied to the returned product.
- The purpose of the RL system.
- The size of the company and its business objectives.
- The structure of the distribution channel.

Table 2. Strategic, tactical and operational decisions during the RL process [6].

Activities	Strategic Decisions	Tactical Decisions	Operational Decisions
Waste Collection	(a) location, quantity and capacity of collection facilities; (b) design of technologies for collection	(a) transportation of waste for collection centers; (b) management of collected waste inventories; (c) means of transportation	(a) collection routes; (b) collection lots; (c) load configuration
Inspection and Classification	(a) location, quantity and capacity of facilities for classification and inspection; (b) training of personnel	(a) inventory management of recoverable products; (b) task assignments; (c) sequencing of tasks: disassembly, cleaning, repairing	Option 3-R to be applied: reuse, re-manufacturing, recycling.
Economic Recovery	(a) technology; (b) effects on the long-term Production Plan	(a) effects on the aggregate Production Plan; (b) recovery lots; (c) management of inventories of recovered products	(a) effects on the Master Production Program; (b) Bill-of-Materials
Distribution	(a) distribution channels; (b) target markets	(a) assignment of products to markets; (b) means of transportation	(a) distribution routes; (b) distribution lots
Elimination	(a) removal systems; (b) target products to be eliminated	(a) management of inventories of non-recoverable products; (b) means of transportation	handling of waste

An important aspect of RL is the determination of its developing entity and scheme [6]. As presented in Table 3, RL can be developed on diverse schemes by the company itself or by a third-party company. Depending of the developing entity, the management of RL can be performed as follows:

- Company. In this case, the company itself designs, manages and controls the recovery and reuse of its out-of-use products. Companies that develop their own RL systems are often characterized by being leaders in their respective markets in which the identification between company and product is very high. They are generally manufacturers of complex and technologically advanced products, designed to recover some of the added value that they incorporated (e.g., Design for the

Environment—DFE, Design for Dismantling—DFDA). Although the ultimate responsibility for the system is the company itself, it is usual for some activities to be carried out by third-parties outside the company (e.g., the collection of products and their transport to the recovery center). The productive process considered to recover the added value of the out-of-use product is usually a complex process, with multiple tasks, in which there is an intensive use of labor. The logistic network that is developed to recover these products is characterized by being a complex, multi-link network, generally decentralized in which the recovered product is reintroduced into the original closed-loop Supply Chain (SC).

- Third-Party. In this case, the company responsible for the introduction of the product in the market does not directly manage the recovery process and this function is performed, for the most part, by third-parties outside the company. In this way the company can either choose to participate in an *Integrated Management System* or hire the services of *Logistics Professionals* specialized in the realization of RL services (e.g., organizations that promote and manage the recovery of out-of-use products for its subsequent treatment or proper disposal, generally these are constituted by suppliers, manufacturers, and distributors, who are the financiers of the scheme).

Table 3. Management schemes of RL systems according to the developing entity [6].

Scheme	**Company**	**Third-Party: Integrated Management System**	**Third-Party: Logistics Professionals**
Business	(a) Market leader; (b) Environmental strategy; (c) Dominant SC position	(a) Small and medium-sized enterprises; (b) Collaboration with other members of the SC	(a) Subcontracted direct logistics flow; (b) Development of the scheme for operational reasons: returns, toxic or hazardous waste
Product	(a) Very differentiated; (b) High added value; (c) Advanced technology; (d) Complex structure	(a) Little differentiated; (b) Low added value and residual; (c) Low technology; (d) Design for Recycling (DFR)	(a) Diversity of products; (b) Obsolete, defective, damaged, toxic or dangerous
Process	(a) Multiple tasks; (b) Intensive labor; (c) Very relevant transport	(a) Complex process; (b) Advanced technology; (c) High initial investment	(a) Simple process; (b) Few tasks; (c) Intensive labor
Market for Recovered Products	Same market as the originals	Different market than originals	(a) Share market in reuse; (b) Distinct market in returns
Network Design	(a) Integration of direct and reverse flows; (b) Decentralized and complex; (c) Closed-Loop; (d) Subcontracted activities	(a) Open Loop; (b) Centralized; (c) Simple with few levels; (d) Significant transport	(a) Open-loop on returns and closed-loop on reuse; (b) Simple and decentralized; (c) Significant transport
Reverse Scheme Goal	Recover elements of high added value	Regulatory compliance on waste	Regulatory compliance on waste and guarantees of consumption.
Management Options	Manufacturing	Recycling	Reuse and Returns
Examples	Xerox, IBM, Hewlett-Packard	Eco-glass, Eco-batteries, Eco-tires	Genco, UPS, GATX Logistics

The schemes presented in Table 3 can be considered starting points to design the appropriate scheme for each company. In order to accomplish this, the organizational schemes in RL require the vital participation of the government, the company, and the society (teamwork). However, in practice, there are deficiencies in the design of these schemes due to the following situations [33]:

- RL is not recognized as a factor that can generate a competitive advantage;
- belief that once the products are delivered, the responsibility of the company ends (to solve it, it is necessary to take into account a life cycle approach linked to the final distribution);
- failure to bridge the internal, external and associated processes in the E-Commerce and the return aspect of products in the SC (associated with process mapping, to understand its scope and complexity);
- assumption that part-time efforts are sufficient to deal with RL activities (RL is not recognized as a complex action that must have its own resources);

- belief that order-time cycles for returned products may be larger and more variable than those associated with the sale or distribution of new products;
- assumption that returned products and recycling and re-use of packaging will take care of themselves if enough time is given;
- difficult separation of products because commonly these arrive mixed at the distribution centers;
- belief that returned products are relatively unimportant in terms of costs, asset valuation, and potential revenues (returns tend to stay longer than new products on direct channels, resulting in high inventory, transportation, and storage costs, and at the same time, revenues decrease due to costs associated with obsolescence and degradation).

3. Reverse Logistics and Regulations in Russia, Mexico, the EU and Japan

3.1. Russian Context

Currently, Russia is one of the countries which can benefit from improvements in their logistic processes to increase its competitiveness within the global context. This is due to difficulties to solve main logistical problems such as infrastructure and environmental constraints in the collection of reusable waste [34]. In addition, there are few scientific publications regarding the return-flows in the Russian literature. Hence, it remains a little studied subject [35].

One of the main difficulties of developing RL in the SC in Russian companies is that the theoretical foundations are not widely studied. Nevertheless, many national organizations are eager to learn from the experience of foreign companies in improving logistic processes to reduce the costs of managing flows in SCs and to seek ways to optimize the movement of goods and materials within logistic systems at different levels [36].

However, this desire is not shared by many Russian companies as business implementations regarding RL are very slow. This is due to the following reasons [37]:

- underestimation of the importance of logistic processes in business activities;
- lack of a unified approach to understand RL in Russian literature (which causes misunderstandings and discussions, as well as making the study and implementation of the best practices of RL in organizations more difficult);
- insufficient explanation in the scientific literature of practical recommendations for the implementation of RL in the activities of Russian companies and evaluation of their effectiveness.

Adding to these reasons, there is a belief that GL and RL lead companies to higher logistical costs [38]. However, within the total logistic costs, the cost of RL is 4.0–6.0% where most of the product returns were initiated by consumers. By analyzing data from diverse global sources, the average percentage of product returns was estimated at 7.0% [39].

In recent years, the rapid development of the logistic market in Russia has given national companies the opportunity to create and design SCs that take into account reverse flows, which is generally an important step towards normalizing the sustainability of SCs [36]. This is an important advance on previous strategies where the recovery of secondary resources was practically deregulated by the government and environmental protection was focused on corrective measures to repair environmental impacts and not on preventive measures to minimize them [35]. Now, the environmental legislation in Russia does not only establish sanctions to the violation of waste collection and use of natural resources laws but establishes a production tax promotion, or subsidy, for companies using innovative technologies and environmentally friendly use of packaging materials in production, especially when recycling is impossible or difficult [38].

Another issue to consider is that most Russian companies do not create special storage facilities for product returns. Thus, it is advisable to allocate space for the implementation of RL processes and establish effective flow records of product returns. Special reception is most convenient for large and medium-sized companies creating their own base point for the collection and separation of returned products. This reception can take place through the creation of a base center, with the participation of several associated companies working in segments of related markets [35]. Another option is to transfer these logistic activities to outsourced companies, which is widely used by Russian companies since handling of returned products is not one of their core competencies.

Regulations for Tire Waste

In Russia, each of its regions has established its own municipal operator to manage the collection of waste, sorting the tires and sending them for recycling, as well as a regional model of waste management. However, not all regions have succeeded as regional officials have failed to make this system economically feasible. In addition, the government was unwilling to create additional financial sanctions in the form of recycling rates for its citizens. In the case of used tires, it is expected that, for any car owner or transportation company, it is best to throw the used tires away, instead of paying money for their proper recycling. As a result, state money remains a crucial part of waste management programs at the regional level [40]. Table 4 presents the main regulations established in Russia regarding the issue of environmental care and waste disposal.

Table 4. Regulations and normativities in Russia (own work).

Normativity	Characteristics
Basel Convention	Regulates the movement of hazardous wastes and recyclables and promotes their environmental management.
Federal Law 89-FZ	Regulates the production and consumption of waste and waste disposal and imposes obligations to recycle or pay an environmental duty.
Federal Law 458-FZ	States that manufacturers and importers of goods must provide the recycling, salvage, reclamation, and disposal of waste generated from the use of such goods including packaging which are no longer of value to consumers.
Federal Law on Production and Consumption of Waste	States that each region has to establish the means for waste processing such as sorting, recycling, sending to a landfill, or incinerating.
Decree 1886-r	States a list of finished goods, including packaging, that must be recycled at the end of their usable life.
GOST-8407-89	This standard applies to worn out tires and chambers that are unsuitable for further use and recovery, as well as tires and chambers rejected by inspection results (hereinafter referred to as secondary rubber raw materials).

In general, the subject of tire collection and re-manufacturing in Russia is not a priority. Just in 2010, over 35.0% of all types of tires were produced and sold compared to the same period of the previous year. Although sales were growing in the budget and the middle segment, in the premium segment, sales declined. This is because, if the car market and the tire market are compared, tire sales depend more on the existing fleet than on new car sales [41].

Experts give the following statistics: more than 700 thousand tons of waste are handled in Russia, and about 70 thousand tons are of old tires that are stored every year. The elimination of these takes place in 2.0–15.0% of the cases while the rest falls on the side of the road, landfills and general waste (which is prohibited by law). According to the accepted classification of rubber products, these products are classified as Risk Class IV of waste. Just in 2015, in Moscow the number of vehicles were expected to exceed 5 million cars, which represents a very pressing problem [42].

Until the 2000s, the recycling of tires and other rubber waste in Russia was a very underdeveloped area. However, in the last decade, the Russian market started to import equipment for the processing of tires from abroad [43] potentially developing the market for the processing of these wastes and making it economically more profitable. Figure 4 shows the RL processes for used tires in Russia [17].

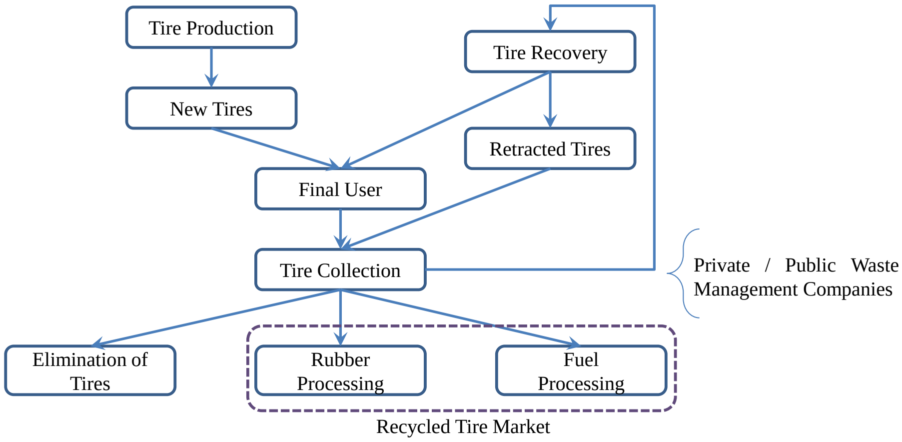

Figure 4. RL processes for used tires in Russia [17].

The current operating capacity of tire processing companies is around 150 thousand tons per year, but, according to the association *Shinecology*, its actual workload rarely exceeds 10.0–30.0%. Additionally, it is estimated (to date) that the amount generated of used tires is about 850 thousand tons per year. The estimated volume of the mechanical treatment of tires in Russia does not exceed 17.0% of the total annual waste of tires. Another 20.0% of used tires are burned. This represents the remaining volume for burial. In this case, for the year 2015, the volume produced annually by the waste of Russian tires reached approximately 935,000 tons per year [44]. The estimation of the total volume of tires to be recycled in Russia in 2010–2015 is presented in Figure 5.

Figure 5. Tires recycled in Russia 2010–2015 (thousands of tons) [44].

The disposal of used tires is carried out only for 2.0–15.0% of this waste and the rest falls on the side of the road, landfills, or general waste (which is prohibited by law). Because in most Russian cities there are no places that are reserved for the permanent or temporary placement of this type of waste, the used tires are often simply thrown on the road on the outskirts and adjacent to the road area [45]. One of the main problems in large cities is that the reception centers for waste tires and the infrastructure intended for it are not commonly seen. As a result, in 2013, only 70 thousand tons of products derived from waste tires (of the more than 700 thousand tons generated) were recycled.

Although there is a public company that is dedicated to the collection of waste throughout the country, according to the tire specialist *Cordiant*, approximately 60.0% of tire recycling in Russia corresponds to just four cities: Volgograd, Moscow, Smolensk and Vladimir. Particularly, in cities with a small population, the collection system of used tires is absent, which means that the ecological situation is unfavorable for these regions.

On average, used tires account for around 80.0% of the previous year's consumption volume [45]. One of the main reasons for this situation is the absence of a developed market for the sale of recycled tires. In addition, Russia does not have an efficient system for collecting used tires for processing. Companies processing raw materials often deal with raw materials which do not guarantee the utilization of capacity [45].

3.2. Mexican Context

Globalization has ensured that the concept of logistic efficiency is an important factor in the competitiveness of countries worldwide—mainly because it gives the direction to follow, assess, prioritize and control the different elements of supply and distribution activities that affect customer satisfaction, both in costs and benefits [46].

In developing countries such as Mexico, with an incipient and unconsolidated recycling industry, it is necessary to improve its structure and activities in order to face the challenges and opportunities arising from the growing concern about environmental problems and the management of products at the end of their useful life [47]. By 2009, there were few companies in Mexico that had capitalized on RL as an area of opportunity to reduce operating costs, increase profits and increase their customers to be more competitive [48].

At present, there has been an increase in the concern of organizations to take full advantage of RL, and thus to be able to minimize costs. However, for small and medium-sized enterprises, this has not been of significant importance when considering the removal of waste, recyclables, perishables or materials. On the other hand, most of the large companies have directed their efforts in the reuse of some materials, designing products bearing in mind the future of recycling, as well as the possibility to cover other markets to classify the returns (e.g., those that can be discarded, reused and repaired, as well as sold throughout other channels or returned directly to the market) [48].

Regulations for Tire Waste

In Mexico, as in many other countries, regulation is the main instrument with which the government seeks to control and influence waste management practices [49]. At the level of federal entities, the normative framework has a moderate delay in relation to the national one. Approximately 40.0% of the Mexican states have defined standards in relation to the general law and the corresponding regulations, while 63.0% have already developed the state programs for the prevention and integral management of wastes [50]. Table 5 presents the main regulations adopted by Mexico regarding the issue of environmental care and waste.

As of 2011, in Mexico, approximately 40 million of used tires were disposed annually and only 12.0% was recycled, which represented about 5 million tires [51]. Mostly, recycling has been linked to the rubber industry [52] and the amount of used tires is additionally incremented by the uncontrolled entry of second-hand vehicles from neighbor countries.

Derived from this, management plans were established for this type of waste. However, as presented in Figure 6, since 2010, the implementation of this plan presented a decrease of 99.89% in the collection of used tires for recycling [14]. This was caused by the following aspects:

- there are no policies to make the collection and transportation of tires economically feasible;
- there are no policies to motivate or regulate the participation of companies specialized into recovery (collection, cleaning and re-conditioning) of this type of waste;
- the management of tire collection has been driven by market conditions; unfortunately, this collection chain is disaggregated from the parties such as the automotive industry and the

manufacturing industry of tires. The main reason for this is the lack of already consolidated networks that add value to the end of the tires' useful life [50].

Based on information provided by the Secretariat of the Environment (Secretaría del Medio Ambiente, SEDEMA) [14] and the Secretariat of the Environment and Natural Resources (Secretaría del Medio Ambiente y Recursos Naturales, SEMARNAT) [50] from the federal government, Figure 7 shows the RL processes for used tires in Mexico.

Table 5. Regulations and normativities in Mexico (own work).

Normativity	Characteristics
Secretariat of the Environment and Natural Resources (SEMARNAT)	Attention to natural resources, biodiversity, hazardous waste, and industrial urban environmental problems.
General Law on Ecological Equilibrium and Environmental Protection (LGEEPA, 1988)	Environmental Impact Assessment, Hazardous Waste, Prevention and Control of Atmospheric Pollution.
Political Constitution of the Mexican United States (24 February 2017)	Article 115° III (Responsibility to collect waste), Transients 17° (Protection and care of the environment) and 19° (Regulation and supervision of integral waste control)
General Law for the Prevention and Integral Management of Waste	Protection of the environment in the field of prevention and integrated management of waste in the national territory with the aim of guaranteeing a healthy environment and promoting sustainable development. This through the prevention and integral management of hazardous waste, urban solid residues and special handling.
NOM-161-SEMARNAT-2011	Establishes the criteria for classifying waste and determining which are subject to management plans, the procedure for their inclusion or exclusion, and the elements and procedures for the formulation of management plans.
NOM-027-SCT2/2009	Land transport of hazardous materials and waste, special and additional specifications for containers, packaging, intermediate bulk containers, portable tanks and transport of hazardous substances and waste materials.
NOM-052-SEMARNAT-2005	Establishes the characteristics, procedure for identification, classification and lists of hazardous waste (Diario Oficial de la Federación (Official Journal of the Federation), 23 June 2006).
ISO-14001	Environmental Management
ISO-26000	Social Responsibility
Basel Convention	Regulates the movement of hazardous wastes and recyclables and promotes their environmental management.
Rotterdam Convention	Promotes shared responsibility in international trade for certain hazardous chemicals and promote their efficient management in order to protect human health and the environment.
Stockholm Convention	Protects human health and the environment from the adverse effects of Persistent Organic Pollutants.

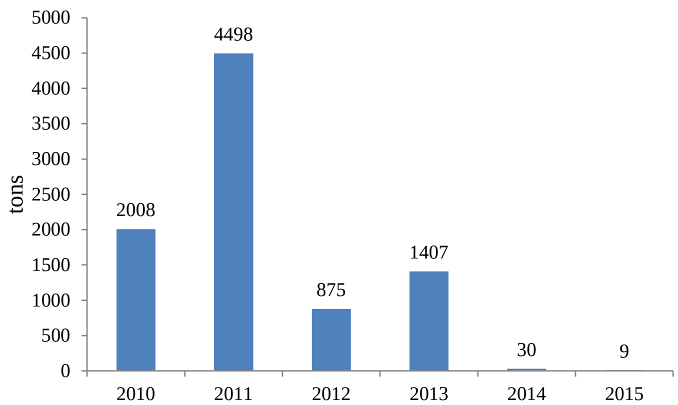

Figure 6. Tires recycled in Mexico 2010–2015 [14].

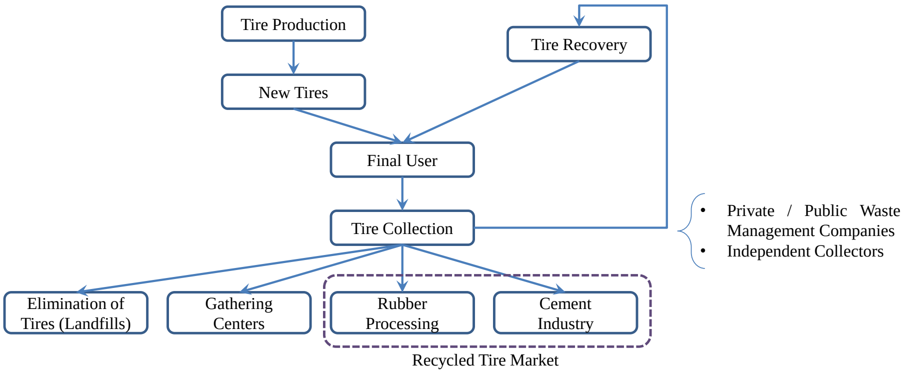

Figure 7. RL processes for used tires in Mexico (own work).

3.3. Context of Japan and the European Union

The United States of America and Japan are some of the first recyclers in the world. In the case of Japan, tire recycling rates were the highest of any country in 2003, averaging 85.0–90.0% with about 855,000 tons of discarded tires [53]. Just in 2017, the total recycled volume increased to 965,000 tons with a recycling rate of 93.0% [54]. Table 6 presents the main regulations adopted by Japan regarding the issue of tire waste.

Table 6. Regulations and normativities in Japan (own work).

Normativity	Characteristics
Basel Convention	Regulates the movement of hazardous wastes and recyclables and promotes their environmental management.
The Japanese End-of-Life Vehicle Recycling Law	Establishment of the characteristics to be met for the disposal of end-of-life vehicles and their components.

In general, scrap tire recycling is addressed as part of solid waste recycling. In addition, cooperative programs that gather tire manufacturers, government agencies and other industrial players, are integrated for scrap tire recycling.

Just as Mexico and Russia, Japan has its own RL processes. As presented in Figure 8, tire waste is obtained from two sources: (a) from users that discard their old tires to replace them by new tires, and (b) from end-of-life vehicles that are disposed completely. Under this scheme, users often have old tires near dealers including tire and car dealers, service stations and auto repair shops. These entities receive the old tires and deliver them to distributors which in turn deliver them to recycling or processing plants. Companies that own service cars, trucks and buses often dispose their scrap tires directly to processing plants as volume is higher. On the other hand, tires from end-of-life vehicles are discarded directly by scrap companies that deliver them to processing plants [53].

In recent years, regulation in the European Union for the tire and rubber industry has changed significantly due to the introduction of stricter requirements for safety, health and environmental purposes, and improved transparency of information to consumers. The complexity of EU legislation is increasing and focuses especially on the area of environment, features, and components that were not so legislated in the past.

The EU is the second largest generator of scrap tires after the United States of America. The EU landfill and end-of-life vehicles (ELV) directives have obliged the respective national governments to address the recycling of scrap tires. Table 7 shows the most important regulations adopted by the EU on the subject of environmental care and waste [19].

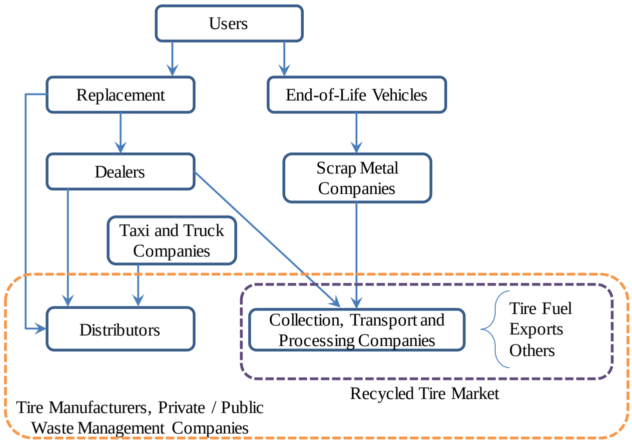

Figure 8. RL processes for used tires in Japan (adapted from [53]).

Table 7. Regulations and normativities in the European Union (own work).

Normativity	Characteristics
Basel Convention	Regulates the movement of hazardous wastes and recyclables and promotes their environmental management.
UNEP/CHW.10/6/Add.1	Technical guidelines for the environmental management of used tires and waste tires.
Royal Decree 1619/2005	Defines the importance of improving manufacturing techniques for tires so that they take longer to wear out, last longer, etc.
Royal Decree 1619/2005 on the Management of Out-of-Service Tires	Protects human health and the environment from the adverse effects of Persistent Organic Pollutants.
Directive 2008/98/EC	This directive establishes measures to protect the environment and human health by preventing or reducing the adverse impacts of waste generation and management, reducing the overall impacts of resource use and the effectiveness of such use.
Directive 2008/98/EC on Waste	This directive constitutes the current regulatory framework for the production and management of waste in the European Union.
Directive 2000/53/EC	This directive regulates the take-back responsibility for car-manufacturers because. Without take-back obligations for end-of-life products, there is almost no necessity for the manufacturer to coordinate the process chain beyond the point of sale.
Directive 2000/53/EC on End-of-Life Vehicles	This directive states that end-of-life vehicles have to be recovered and their tires have to be removed before they are scrapped.
Directive 1999/31/EC on the Landfill of Waste	This directive bans the disposal and stockpiling of tires on landfills.
Directive 2000/76/EC on Incineration of Waste	This directive prohibits combustion of end-of-life tires in old cement kilns.

Although the EU has left the method of implementing the directives at the discretion of the member countries, and with the deadlines for the implementation of the rapidly approaching directives, recycling rates are expected to increase in establishing the viable industry [53]. Within the EU, countries such as Spain, Sweden and France have achieved 100.0% recycling rates since 2011 [19].

In the EU, the tire industry operates with two schemes: (1) the *Industrial Liability Scheme*, where producers work together with other industry stakeholders to assume responsibility for the recycling and management of waste tires; and (2) the *Liability Scheme of the Producer*, where producers are responsible for the recycling of used tires. In both cases, consumers are responsible for the collection and recycling costs [53].

All member countries of the EU have to be in compliance with EU legislation in transposing directives into local legislation. They are free to set up national initiatives to achieve EU objectives. Tire manufacturers also face increasing environmental pressure from the general public and other stakeholders on dumping stocks [55].

For these reasons, it is in the interest of the tire industry in the EU to remain proactive and assume collective responsibility for the management of out-of-use tires. To date, there are three different schemes for the final management of these wastes. These are described in Table 8.

Table 8. Systems for the final management of out-of-use tires.

Extended Producer Responsibility	Liberal System (Free Market)	Government Responsibility
Systems with take-back obligations	The legislation sets the objectives to be met but does not designate those responsible.	Government responsibility financed through a tax.
The original manufacturer has a duty of care to ensure that the waste from the products it has created is disposed of responsibly, in an environmentally sound manner.	All the operators in the recovery chain contract under free market conditions and act in compliance with the legislation.	Each country is responsible for the management of tire waste.
	This may be backed up by voluntary cooperation between companies to promote best practice.	It is financed by a tax levied on tire producers and subsequently passed on to the consumer.

In this regard, the countries that have achieved a 100.0% recycling rate (i.e., Spain, Sweden and France) have operated under the Extended Producer Responsibility system [19]. This system uses economic incentives to encourage manufacturers to design environmentally friendly products by making them responsible for the costs associated with their disposal at the end of their useful life. Under this system, recycling costs are integrated within the product price. Figure 9 presents the general RL processes for used tires in the EU [53].

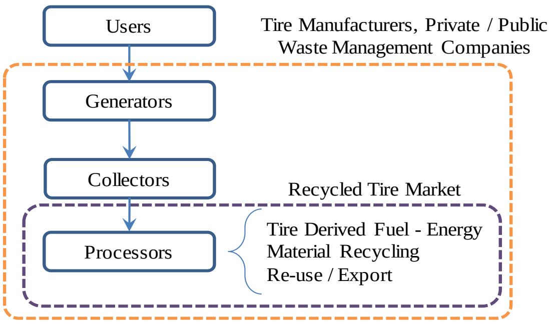

Figure 9. RL processes for used tires in the EU (adapted from [53]).

3.4. Entities Involved within RL Processes for Used Tires

As discussed in Section 2, the main RL processes consist of recycling, re-manufacturing, and reuse. Within the context of tire waste, the recovery systems associated with these processes consist of the following networks [6,56]:

- Networks for Recycling of Tires. They are usually simple structures, with few centralized links that are characterized by requiring, for an efficient management, a high volume of inputs (tires of waste) generally of little unit value. The high transformation costs determine the need for high utilization rates of these networks and the search for economies of scale.
- Networks for the Re-manufacturing of Tires. Its main objective is the recovery of parts and components of tires with high added value. In these systems, the original manufacturers usually play a very important role, sometimes being solely responsible for the design and management of RL systems. The design of the network responds to a multi-level, decentralized typology, for which synergies are usually sought with the direct channel.
- Reusable Tire Networks. In these systems, the recovered tires are reintroduced in the SC once the necessary cleaning and maintenance operations have been carried out. They tend to be decentralized structures where both original and reused tires circulate simultaneously and in which the cost of transport appears as the most significant.

Based on these networks, Tables 9–11 present the main entities which are considered to be involved in the main processes of collection, recycling and reuse of used tires [52].

Table 9. Entities involved in the collection of tires.

Entity	Objectives	Activities
Federal Government	Development of the collection market	(a) Facilitate and make attractive the collection and gathering business; (b) Develop economic stimuli and incentives; (c) Establish a list of recyclers and collectors.
	Establishment of collection processes	(a) Define the rules of the States and Municipalities concerning the collection by their public services; (b) Supervise compliance with the provisions.
	Establishment of facilities for gathering	(a) Define the rules of the State and Municipalities concerning the collection centers; (b) Monitor compliance with the provisions.
State and Municipal Government	Installation of a collection system	(a) Define the rules of the State and Municipalities concerning collection centers; (b) Monitor compliance with provisions
	Installation of storage centers	(a) Adapt the area and request permits; (b) Define rules and charges; (c) Allocate building resources; (d) Develop economic incentives for private initiative.
Government (user)	Adequate provision of tires	Direct used tires to pickers and collection centers.
Large Users	Adequate provision of tires	Direct used tires to pickers and collection centers.
Manufacturers, Importers and Traders	Dissemination of the collection centers for this purpose.	Reinforce with distributors the collection of used tires to authorized sites.

Table 10. Entities involved in the recycling of tires.

Entity	Objectives	Activities
Government	Development of the recycling market	(a) Facilitate and make attractive the business of recycling; (b) Develop economic stimuli and incentives; (c) Promote and fund research programs and grant support to educational institutions and students; (d) Regulate other recycling schemes; (e) Make associations of recyclers and promote conventions; (f) Government procurement of products under recycling specifications; (g) Give preference to new developments for the use of recycled used tires and recycle content of by-products of the used tires
Manufacturers, Importers	Cooperation agreements	(a) Establish agreements between Technical Committees to reach consensus with the Chambers and Associations of the branch; (b) Target the collection of used waste tires to meet the needs of recyclers and grant technical support; (c) Grant support to educational institutions and students; (d) Conduct research programs for the recycling of waste tire components
Recyclers	Involvement	Participate in activities promoted by government and private enterprises

Table 11. Entities involved in the reuse of tires.

Entity	Objectives	Activities
Government	Development of the reuse market	(a) Facilitate and make attractive the business of reuse; (b) Develop economic stimuli and incentives; (c) Make a list of potential companies for reuse of used waste tire; (d) Promote exhibition meetings or conventions; (e) Government procurement of products under reuse specifications; (f) Give preference to new developments for used products
(a) Potential companies for reuse; (b) Same manufacturing company	Involvement	Participate in activities promoted by the government and private enterprises

4. Proposed RL Strategy for Tire Waste

As previously discussed, tires at the end of their useful life are one of the biggest concerns with regard to the environment due to the pollution it causes. In addition, they have a practically unlimited degradation time due to the reticulated structure of rubbers and the presence of stabilizers [57].

Through the tire recycling process, the main materials that make up the tire can be used, such as: 70.0% rubber powder, 25.0% steel, and 5.0% textile fibers. According to the importance of this waste in terms of its composition material and its role in society, its recycling becomes vital for the care of the environment. In order to do this, and due to the impact that it generates all over the world, to a lesser or greater degree, mainly in countries like Russia and Mexico, it is indispensable to visualize it not only as a matter of recovery of recyclable material but as a total economic system.

The implementation of RL involves environmental and economic benefits in the different areas of implementation. In particular, the economic benefits are dependent on the degree of implementation in the process of transformation and distribution of companies. As for the recycling of products that have some degree of contamination such as tires, the economic benefits are obtained as follows:

- If efficient processes of re-use or re-manufacturing of goods (whether fast and inexpensive) are established, the cost of raw material and production of new goods can be reduced (instead of re-making a tire, re-conditioning of a used tire can be cheaper).
- The collection of used tires that are candidates for re-conditioning must be efficient (e.g., it must be of minimum time). Therefore, the optimization of collection routes can provide faster and cheaper re-utilization processes that can substitute a percentage of the purchase cost of raw material or manufacturing (from scratch) of a new product.
- Improvement in the environmental aspect is a consequence of these measures, and better government support (investment funds) can be accessed if these practices are encouraged.
- If a fixed area of re-conditioning of tires is established, it will be possible to have an area that receives raw material (in this case, used tires) that can give sustenance to inventory in case of breakdown. This also involves savings and service level improvement.
- On the other hand, tires that have reached the end of their useful life (it is not possible to re-condition them) support other industries (generate income).

For this reason, two strategies focused on re-manufacturing (or re-treading) and diversification are considered.

4.1. Re-Manufacturing or Retreading Strategy

The tire is mostly discarded due to wear of the tread, which has between 10.0% and 20.0% of all the material and the energy contained in it [58]. The process of retreading involves placing a layer of non-vulcanized rubber on a worn tire that will cover the tire's tread and shoulders. The process is then completed by placing the tire inside a mold so that, by means of pressure and temperature, the new drawing is inserted therein.

The re-manufacturing of this waste is a strategy that takes care of the environment, as it recovers the value of the components of the tire waste, which would otherwise end up in landfills. There is no doubt that the tire retreading process leads to significant savings in energy demand by 66.0% in production capacity and materials in the manufacturing process due to the minimization of raw material requirements [59].

The costs of retreaded tires are 30.0–50.0% less than the cost of a new tire. This makes it attractive to consumers, such as truck fleet operators who travel long distances and demand higher tire replacement rates. This sector represents the biggest retreading industry due to the following aspects:

- Maintenance and replacement of tires is the third highest cost for fleet operators, after labor and fuel.
- The renewal rate for tire replacement is much higher for heavy truck fleets.
- Tire retreading is desirable from the point of view of economic and material saving.

According to the Michelin Factbook (2001), retreaded tires account for 44.0% of the total tire replacement market for heavy truck tires. Retreading has an environmental impact in terms of processing of raw materials, manufacture and use. Among these impacts, the following can be mentioned:

- Reduction of energy savings in the field of transient technological changes in tires;

- Reconditioning of energy-saving tires in the field of inefficiency of degradation of retreaded tires compared to new equivalent tires;
- Energy saving of retreading of tires in the scope of the variations of the product.

According to the Tire Retread and Repair Information Bureau (TRIB), retreaded tires can last 75.0% to 100.0% of the life of a new tire, based on the quality of the retreading process. Retreading has its advantages and disadvantages, which are shown in Table 12.

Table 12. Advantages and disadvantages of waste tire retreading [60].

Advantages	Disadvantages
(a) Extends the useful life of the tire; (b) It uses many of the original materials and much of the original structure; (c) The net result is a decrease in materials compared to the manufacture of new tires; (d) Rubber extracted from used tires prior to retreading is often sold as crushed rubber for other purposes; (e) The energy used is lower compared to the original manufacture: the energy used to retread a tire is 400 MJ while the manufacture of a new tire requires 970 MJ	(a) Concern for the volatile organic components emanating from solvents, adhesive agents and rubber compounds during vulcanization; (b) Smell can also be a problem in some places; (c) The process generates a large amount of waste

This strategy can use the criterion of creating a network for the re-manufacturing and tire re-use network. The first network is aimed for the recovery of the tires and their latter re-manufacture. In this type of network, the original tire manufacturers usually play a very important role, being sometimes solely responsible for the design and management of RL systems, whose design responds to multilevel, decentralized characteristics, for which synergies are sought with the direct channel. The second network is aimed for re-introducing the recovered tires into the SC (vulcanization) once the necessary cleaning and maintenance activities are carried out. In these networks, there are decentralized structures whereby original and re-used products are simultaneously circulated and in which the cost of transport appears as the most significant [6].

4.2. Diversification Strategy

To produce recycled products of equivalent quality and price, the industry must invest heavily in new technologies. Doing so would be taking advantage of a cheap resource, which allows them to generate secondary products for sale. This investment creates an opportunity to close the recycling cycle and therefore to close the SC, paying attention not only to production and processing, but also to the collection of the waste generated to be used as raw material for other processes within the company (or to open a channel with new clients).

One of the materials with greater presence in tires is the dust generated from them, as well as the steel and the textile fibers. The market for these materials is very broad and their use can be seen in family parks, sports courts, roads, among other elements, which are presented in Table 13.

Table 13. Uses of tire components [60].

Products	Use	Potential Clients
Tire Dust	(a) Parks for children, sports tracks, asphalt; (b) Artificial grass; (c) New tires, rubber and energy source; (d) Home insulation, waterproofing; (e) Security plates; (f) Shoe soles, carpets & rugs; (g) Conveyor belts	(a) Construction equipment; (b) Suppliers of building materials; (c) Plastic Products; (d) Insulation; (e) Government; (f) Cemeteries; (g) Steel companies
Steel	Blast furnaces, asphalt fillers	(a) Construction equipment; (b) Suppliers of building materials; (c) Steel companies
Textile fibers	(a) Artificial grass; (b) Shoe soles, carpets & rugs; (c) Clothing	(a) Suppliers of building materials; (b) Plastic Products; (c) Insulation

Diversification has its advantages and disadvantages, which are shown in Table 14.

Table 14. Advantages and disadvantages of waste tire retreading [60].

Advantages	Disadvantages
It increases the demand based on supply. However if the company focuses on offering a single product, a change in the market may affect its performance. For this reason it is important that the company offers the consumer several purchase alternatives.	(a) Lack of knowledge of the market: by offering new products and services, there is the possibility of not having enough knowledge and experience of the market to which it is intended, affecting the financial resources of the company; (b) Cost: it must have a reliable economic stability so that the production of new products will not affect the company.

For this strategy, a recycling network could be used. This type of network usually has simple structures, few links and it is centralized. These networks are characterized by requiring, for an efficient management of the same, a high volume of recovered products which generally are of little unit value. The high transformation costs determine the need for high utilization rates of these networks and the search for economies of scale [6].

4.3. Integrated RL Scheme

Both strategies show the advantages and disadvantages of its implementation within the framework of RL. However, it is necessary to know what the interests of the company are in order to take the best decision to generate greater benefits, but how does RL can influence the tire manufacturing process? The proposed adaptation of the RL process is described in Figure 10.

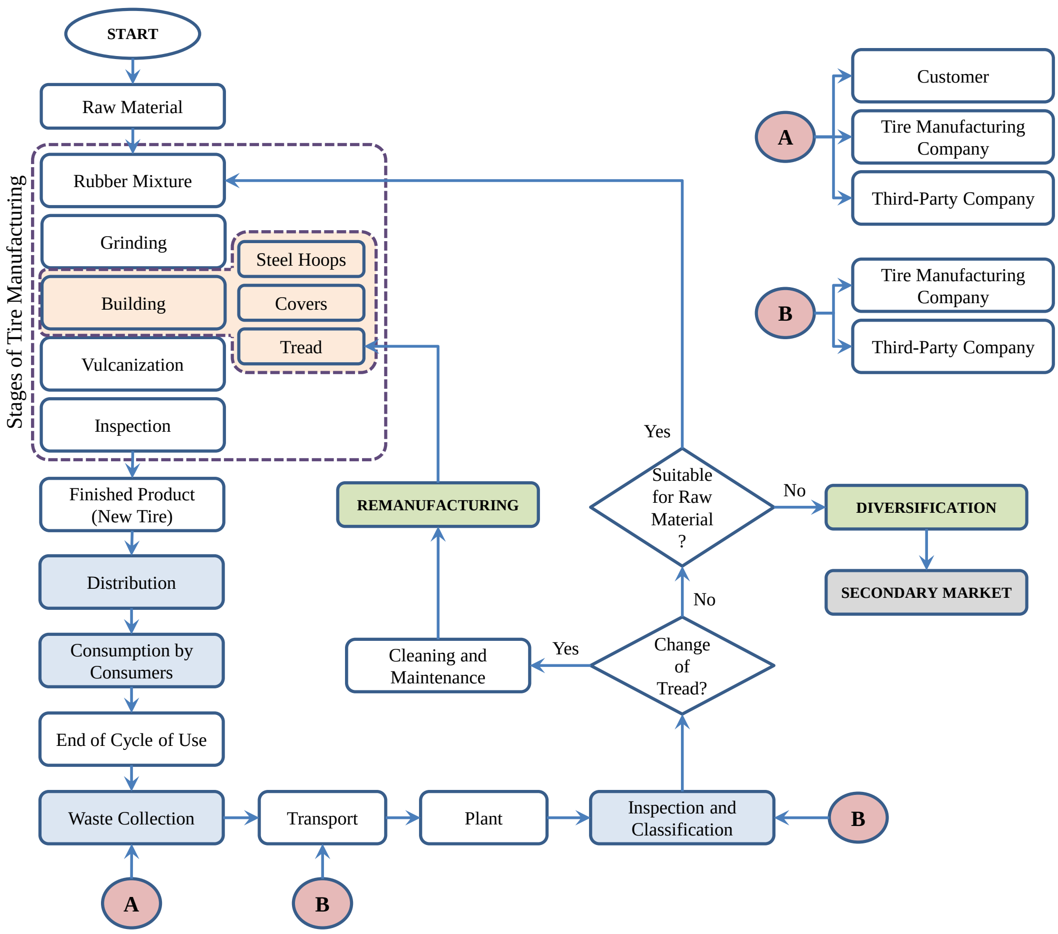

Figure 10. RL structure for tires (own work).

As presented in Figure 10, after the customers use the tires and they reach the end of their cycle of use, RL becomes a vital part of the proposed waste management strategy. In addition, it is important to observe that this RL structure has the purpose of minimizing the generation of non-recoverable waste, thus reducing the source of contaminants. This is the reason for the elimination process being absent in Figure 10.

In general, the management of the RL structure can be performed by the following entities:

- a third-party (public or private) company can perform the whole process of collection, classification, and re-manufacturing of the out-of-use tire;
- the manufacturing company itself can extend its participation within the RL process assuming some responsibilities.

While companies (either the manufacturing company, or third party companies) are considered for most of the RL processes, the users or customers are considered as a vital part of the waste collection process. This is proposed to support a culture of sustainable waste management as achieved in Japan and the EU. Nevertheless, it is important to point out that, as in the EU, good law legislation is the key for the success of the RL processes [26]. In Mexico, tax incentives can improve the collaboration of users and private entities in the collection process. Particularly, the adaptation of the *Extended Producer Responsibility* system, which has been successfully implemented in the EU and Colombia, can be of significant benefit in Mexico and Russia. In this aspect, while Russia is not a member of the EU, since 2015, there have been amendments to the Russian 1998 *Federal Law on Waste from Production and Consumption* to implement legislation similar to those of the EU for extended take-back obligations (i.e., collection and recycling) on producers and importers of certain products and packaging.

In addition, the proposed stages for waste collection can be extended with different logistic networks for recovery. As an example, Figure 11 presents the logistic chains proposed in [61] for tire waste management where:

- The first logistic chain considers that the product is recovered by the same company that manufactures it (thus, the company only recovers the tires that were manufactured by it).
- The second logistic chain considers that the company recovers (1) its own tires, and (2) tires manufactured by its competition (e.g., other companies), leading to reach a greater volume of tires to carry out its processing.
- The third logistic chain considers that the entire recovery process is carried out by a third-party company, which may be contracted by the manufacturer whose product is collected for the same purpose. This chain can also be extended for the creation of other products (diversification), either by means of this contracted company or by the manufacturing company itself. The third-party company can also perform the whole process or simply be a part of it.
- The fourth logistic chain is related to the previous chain and it represents the case in which the company that is collecting the product does it for a different manufacturing process than the production of tires. This leads to the diversification for new markets.

Regarding the specific stages of re-manufacturing and diversification, the alternatives reviewed and discussed in Sections 4.1 and 4.2 can be extended with the following novel approaches:

- Manufacturing processes focused on decreasing rolling resistance of tires. This can lead to improving fuel efficiency, reducing CO_2 emissions, and extending the useful life of the tire [54].
- Standard use of the "Reduce Index" (Re Index) to objectively measure and assess processes focused on achieving a longer wear life of tire for different vehicles [54].
- Use of recycled tire crumb (RTC) for the manufacturing of construction materials. The RTC has been identified as a promising approach to create lightweight cellular concrete (LCC) due to its insulation properties regarding sound, water, and temperature [25]. Countries with regions with extreme weather conditions such as Russia can get benefits from this proposal.
- Recycling processes based on state-of-the-art advances in chemical studies on the effects of amount, size and morphology of rubber granulate grains for the creation of modern polymer-rubber composites from used tires [26].

- Extend on thermo-mechanical devulcanization based on extrusion as a standard for recycling on an industrial scale. As discussed in [23], it is the most environmentally appropriate approach to tire recycling in comparison to chemical, ultrasound, microwave, and mechanical devulcanization.

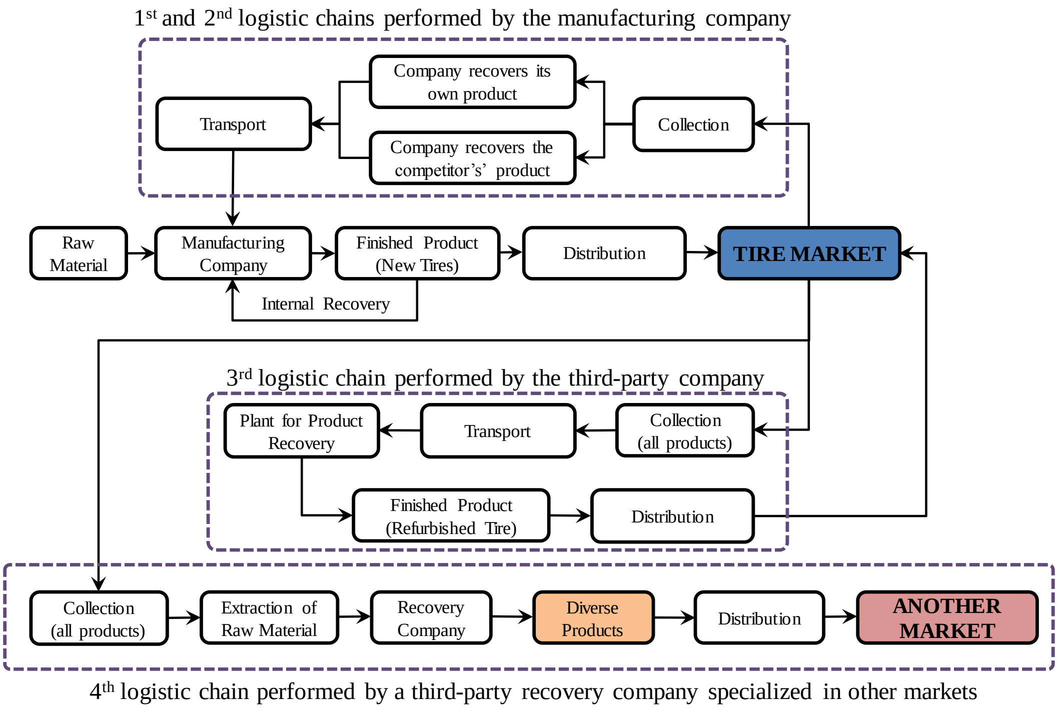

Figure 11. RL recovery process for tire waste (adapted from [61]).

5. Discussion on Findings

The current environment requires companies to increase the utilization of resources and optimize their practices through the incorporation of logistic processes. The consideration of a reverse flow in the logistic functions can support these objectives. Specifically, recycling of used or worn tires is the most urgent aspect to achieve sustainability within the tire industry.

According to Russian legislation, the organization of waste collection and recycling is under the responsibility of local authorities. However, classification and recovery are rarely performed by the Russian waste management system by the following situations: shortening of legislative regulation, the absence of strict requirements to separate waste, weak public awareness, and lack of collection stations and markets. Additionally, there is also a low efficiency in garbage trucks, and lack of transfer stations and incineration plants [62].

Not having an effective recycling process leads to the generation of waste. In Russia and Mexico, the most common form of waste treatment is landfill disposal. However, most landfills in operation are already overloaded and some constitute environmental and epidemiological hazards. Landfill problems in Russia and Mexico are due to non-compliance with environmental and sanitary standards, and closing of landfills without waste recovering. To reduce the dependence on landfills, the development of effective recycling processes can be established by reinforcing regulations, tax incentives, and improvement of disposal technologies (e.g., by-products or energy from waste). For this, business strategies can improve the economic outcomes of recycling. However, it is important to mention that, even with the latest recycling or re-manufacturing technologies, landfill is the main disposal strategy in the short and medium term.

In this regard, countries within the EU, such as Spain, Sweden and France, have achieved 100.0% recycling rates since 2011 [19], and the *Extended Producer Responsibility (EPR)* system has proved to be a suitable mean to accomplish this objective. This system can be adapted to Mexico and Russia as it was performed in Colombia [21]; however, it is important to consider the following difficulties:

- while incentives are considered within the EPR, and the company can rely on third-party companies for collection, recycling and re-manufacturing (including diversification), some processes may be too expensive and/or complex. This can limit the intended impact or commitment of all entities within the SC;
- implementation and compliance of new RL legislation may represent additional administrative and economic burden to local governments;
- among the critical factors for recycling are the management and transportation costs which must be performed by the responsible entity. In general, the collection of tire waste is not only carried out by the public (i.e., government) companies, but also by private companies that use this waste as raw material for their production processes (e.g., diversification). While transportation costs have reduced the collection tasks due to inefficient route planning, there is also an inefficient cooperation between public and private companies to accomplish these tasks.

The conceptual RL model presented in Figure 10 can support the decisions regarding the main processes to be considered for a waste management strategy. In addition, it can motivate the participation of companies in transportation and/or diversification through the appropriate visualization of the RL processes.

In this model, retreating or re-manufacturing have the following economic and environmental advantages for sustainability:

- savings in the energy used for production by 66.0%;
- 30.0–50.0% cheaper than the manufacturing cost of a new tire;
- a re-manufactured tire can have a useful life of 75.0–100.0% when compared to a new tire;
- very appropriate for heavy truck operators where the tire replacement rate is high.

On the other hand, market diversification represents an important investment opportunity that may be an option to close the SC cycle that includes both Direct and Reverse Logistics, as it would not only be paying attention to the process of production, but also to the problem of generated waste. This waste can be used as raw material within the SC's production process, or be used as raw material for new production lines designed to launch new products. This would help the companies to keep current customers or to obtain new customers by opening their doors to a secondary market. In this case, technologies such as those presented in [23,25,26] can make recycling and diversification more environmentally and economically viable.

However, as previously discussed, governmental and financial support is needed to invest in high-level recycling technology, and, at the same time, to obtain the highest rates. The attractiveness of secondary products and energy from waste also needs to improve economic and legal instruments, and public campaigns and procurement should be used to raise awareness of waste as a valuable resource. In addition, it is important to mention that landfills, even with future technologies and regulations, cannot (and will not) be eliminated completely in the short and medium term, independently of the RL strategy.

6. Conclusions

The present work defined a conceptual RL model for the tire waste management systems of Mexico and Russia due to an absence of work and consensus regarding RL strategies in these countries. For this purpose, a comprehensive review of tire waste management strategies in the EU and Japan, leading countries in recycling and sustainable practices, was performed. In addition, the current status in Mexico and Russia was reviewed considering the factors highlighted by the United Nations for the establishment of waste management systems.

This review provided the background to identify two specific RL processes: *re-manufacturing* and *diversification*, as a means to make a tire waste management system economically accessible and sustainable. These processes were integrated within an RL model considering the most standard processes performed in the EU where the Extended Producer Responsibility (EPR) is a recommended scheme that has provided benefits in countries such as Spain, France, Italy, and Colombia. Finally, a review on recycling technologies for diversification was discussed to support economic benefits.

Although a better strategy over the reviewed strategies cannot be assured due to the different regional conditions of financial mechanisms, regulations, involving entities and technologies established in each country, within the context of Mexico and Russia the proposed RL model can provide the guidelines to incorporate *re-manufacturing* and *diversification* in their waste management systems as no previous works concerning these countries have been reported. In addition, the present work can be improved regarding its limitations as no empirical research has been performed in Mexico and Russia regarding quantitative assessment of RL processes. This assessment represents also an approach to improve other strategies as those performed in the EU, Japan, Colombia, Italy and Romania.

Thus, as future work, the following aspects are considered:

- design of a Green-Reverse logistic model (e.g., by means of mixed integer linear programming) to improve the distribution network required for the collection, recycling, and diversification tasks;
- incorporation of economic variables within the RL structure to establish an efficient business model between all entities involved in the recycling process;
- incorporation of inventory supply strategies as a mean to optimize tire waste processing.

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